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TECHNOLOGICAL SCHEMES FOR THE PROCESSES OF PREPARATION AND MILLING BINARY GRAIN MIXTURES AND BIOCHEMICAL EVALUATION OF PRODUCED PRODUCTS

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KEY WORDS:
wheat, flax, binary grain mixture, grinding technological scheme, wheat-flax flour, biochemical assessment.

ABSTRACT
A study of the preparation and milling of a grain mixture containing 7% of flax seeds has been carried out in order to obtain a composite wheat-flax flour, in which the entire biopotential of flax seeds was preserved. It was revealed that the preparation of the components of the grain mixture should be carried out independently, in parallel flows. During the wheat grain preparation the cold conditioning was carried out, the modes of which were the following: humidity — 15.5%, dwell time in the water — 24 hours. The optimal conditions for milling the wheat-flax mixture have been determined, which are the following: yield (%) / ash content (%) in 3 break systems (in terms of the 1st break system — grain) for the first break system — 53.5 / 1.00; for the second break system. — 22.2 / 1.11; totally for the first and the second break systems — 75.7 / 1.035; totally for the first, the second and the third break systems — 81.0 / 1.1. The technological schemes have been developed and the new varieties of wheat-flax flour with predetermined technological properties and increased nutritional value have been formed. The approximate indices of yield and quality of the new wheat-flax flour varieties are the following: Flour A — yield 45–50%, lipids 3.6–4.0%, protein 13–13.5%, ash 0.55–0.70%, whiteness — 50 conventional units; Flour B — yield 20–25%, lipids 5.5–6.0%, protein 14–14.5%, ash 0.9–1.25%, whiteness — 22 conventional units; Flour C — yield 70–75%, lipids 4.5–5.0%, protein 13.6–14.0%, ash 0.75–0.90%, whiteness — 36 conventional units. It was indicated that the total lipids content in flour from two-component mixtures increases by about 4 times, and the total protein content in the studied samples increases by 1–2%. The content of linoleic acid (ω-6) in wheat-flax flour samples is 1.6...3.3 times higher than in wheat flour; the content of linolenic acid (ω-3) in wheat-flax flour samples is 36.8...57.2 times higher than in wheat flour (taking into account the total lipids content in the samples). The enrichment of wheat flour due to flax seeds allows to make up the deficiency of PUFA family in the diet of a modern person and to obtain products on a grain basis of a balanced composition.

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1. Introduction

The enrichment of the products of wheat grain processing with proteins, minerals, and dietary fiber is achieved by introducing the milling products of some cereal crops into wheat flour. This solution has found a wide application in the bakery production in the form of so-called composite flour mixtures. However, in recent years the demand of grain products enrichment with essential fatty acids, especially with linolenic acid (the ω-3 family of fatty acids), the deficiency of which negatively affects human health, has emerged [1,2,3,5,6].

Analysis of the lipid composition of various oilseeds shows that linseed oil, as a source of unsaturated fatty acids of the ω-3 family, has an absolute advantage. The main fatty acid of the oil from flax seeds is linolenic acid, the relative content of which varies according to different sources from 47.5% to 68.1% [3,5,7].

The problem of flour enrichment with essential fatty acids is currently solved by using crushed linseed cake (flax meal). The use of linseed cake has several disadvantages. First of all, according to various authors' studies the content of such flax meal in the composite mixture should be 15–25% to provide essential fatty acids in the required amount, but such content significantly degrades the consumer properties of bread [4,5]. The direct use of flax seeds will allow one to significantly (3–4 times) reduce the content of products of flax seeds processing in the composite mixture at maintaining the amount of unsaturated fatty acids, primarily of essential linolenic acid, necessary in terms of composition balance [4,8].

The introduction of flax seeds in the mixture sets the task of developing technology for processing mixtures. First of all, it is necessary to determine the milling conditions of such mixtures (parameters and milling modes), each component of which has its own specific features.

The aim of the research is the development of technological schemes for the preparation and grinding of binary grain mixtures based on wheat and flax seeds and a biochemical assessment of the newly formed varieties of wheat-flax flour obtained by joint grinding of a wheat-flax mixture.

2. Materials and methods

The object of the study was wheat grain and seeds of white and brown seed flax. Table 1 and Table 2 show the technological properties and chemical composition of the initial components of the grain mixture.

The components of the grain mixture are characterized by an average level of values both in chemical composition and technological properties and can be considered as quite representative. The content of flax seeds in the mixture was determined based on the recommended levels of consumption of food and biologically active substances [9,10] and averaged about 7%.

To study the milling and production of wheat and wheat-flax flour, the RSA-5 reduction and sorting unit with corrugated roll-

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ers for break systems (P-10 $^{1}/_{cm}$) and microrough surface rollers for reduction systems, the laboratory plansifter and the laboratory bran finisher were used. The whiteness of flour (WF) was determined by measuring the reflectivity of a densely smoothed flour surface using a photovoltaic device (GOST 26361–2013), ash content (Z) — by burning flour and bran, followed by determination of the fireproof residue mass (GOST 27494–2016). The total protein content was determined by the Kjeldahl method (N×6.25) (GOST 10846–91); lipids content — according to Soxhlet (GOST 29033–91); fiber content — according to Kuschner and Hanek; starch content — according to Evers (GOST 31675–2012); reducing sugars according to the Bertrand method; soluble protein — according to the Lowry method. Determination of the fractional composition of proteins according to Osborne: albumins were isolated using distilled water, globulins — using a 10% NaCl solution, prolamines — using 70% ethanol, and glutelins — using a 0.2% NaOH solution. Enzymatic activity of proteases was determined by the modified Anson method using bovine serum albumin as a standard substrate; amylase activity — by the colorimetric method according to the amount of starch hydrolyzed based on an assessment of the color intensity of the starch-iodine complex; the activity of alkaline and acid lipases was determined by the titrometric method by the amount of fatty acids formed [11]. Fatty acid composition — by gas chromatography (gas chromatograph 6890N with mass-selective detector Agilent 5975C, USA).

Table 1

Technological properties of the initial components of the grain mixture

Agricultural crop	Moisture, %	Mass of 1000 seeds, g	Test weight, g/l	Vitreousness, %	Medium geometric grain sizes, mm a-width, b-thickness, l-length
Wheat	12/2	44.66	769	52	a = 3.6 b = 2.9 l = 6.5
Flax seeds: white	5.2	8.40	668	—	a = 2.5 b = 1.2 l = 5.2
Flax seeds: brown	5.1	8.37	667	—	a = 2.5 b = 1.2 l = 5.1

Table 2

The chemical composition of the initial components of the grain mixture

Agricultural crop	Protein, %	Fat, %	Starch, %	Cellulose, %	Gluten, %
Wheat	13.43	1.83	66.8	2.2	24.7
Flax seeds: white	24.68	39.80	5.2	15.0	–
Flax seeds: brown	24.42	37.33	5.1	15.1	–

The analyses were performed in the samples of wheat-flax flour, presenting the results as average arithmetic ones. The discrepancy between parallel assays did not exceed 3% of the average arithmetic value with the confidence probability P = 0.95.

3. Results and discussion

Processing of grain mixtures, the components of which have significant differences in physical and chemical properties, is a rather complicated task [12,13,14,15].

The study of the processes of preparation and milling of a grain mixture containing flax seeds was carried out using 93% wheat grain and 7% flax seeds content. The conditions for the joint processing of wheat grain and flax seeds are the separate preparation and thorough mixing of the components immediately before milling. The content of flax seeds in the mixture was determined in accordance with the "Recommended levels of consumption of food and biologically active substances", it averaged about 7%. During the wheat grain preparation the cold conditioning was carried out, the modes of which corresponded to "The rules of organization and process control at flour mills", humidity — 15.5%, dwell time in the water — 24 hours.

Analysis of the geometric sizes of flax seeds and wheat grain shows the impossibility of their joint cleaning. The preparation scheme should consist of independent preparation flows.

The scheme of the two-factor experiment for determining the optimal conditioning parameters is presented in Table 3.

Table 3

Estimated and actual moisture content of the original wheat grain

Milling number	Estimated moisture, %	Actual moisture, %	Dwell time in the water, hour
1 (control)	16.0	14.7	24
2	16.5	15.2	24
3	16.5	14.9	12
4	15.0	14.4	18
5	14.5	13.6	12
6	14.5	13.7	24

The results of grain mixtures milling are presented in Table 4 and Table 5.

Table 4

Yield (Y) flour and bran,%

Technological system	Yield (Y), %				
	Milling № 2	Milling № 3	Milling № 4	Milling № 5	Milling № 6
Break I	8.4	11.9	8.3	8.3	9.5
Break II	10.8	11.9	7.7	7.7	8.8
Break III	3.6	3.3	4.3	4.0	3.8
Reduction system 1	35.6	35.4	31.4	30.7	32.1
Reduction system 2	5.2	2.5	11.0	11.7	8.4
Reduction system 3	2.4	2.9	5.0	6.0	3.8
∑ flour	66.0	67.9	67.7	68.4	66.4
Bran from break systems	23.2	18.5	19.0	16.3	19.5
Bran from reduction systems	10,8	13.6	13.3	15.3	14.1
Bran from break systems / bran from reducti on systems	2.15	1.36	1.43	1.07	1.38
∑ bran	34.0	32.1	32.3	31.6	33.6

Table 5

The results of laboratory grinding on the whiteness of flour, units

Technological system	Whiteness (WF), units				
	Milling № 2	Milling № 3	Milling № 4	Milling № 5	Milling № 6
Break I	73	69	69	67	66
Break II	56	52	53	51	51
Break III	37	31	31	30	29
Reduction system 1	55	51	50	50	50
Reduction system 2	36	29	36	35	33
Reduction system 3	28	23	24	21	23

Statistical analysis of laboratory milling results using the MINITAB14 program revealed statistically significant linear regression equations. The result of statistical processing of the dependence of flour whiteness on conditioning parameters (Table 3) is presented below.

Regression Analysis: WF2 versus Y2
The regression equation is
WF2 = 72,45–0,2759 Y2
S = 2,39544 R-Sq = 91,0%
R-Sq(adj) = 88,8%

Regression Analysis: WF5 versus Y5
The regression equation is
WF5 = 67,16–0,3066 Y5
S = 1,92102 R-Sq = 95,3%
R-Sq(adj) = 94,2%

Regression Analysis: WF3 versus Y3
The regression equation is
WF3 = 69,93–0,2675 Y3
S = 1,95253 R-Sq = 93,2%
R-Sq(adj) = 91,5%

Regression Analysis: WF6 versus Y6
The regression equation is
WF6 = 67,16–0,3051 Y6
S = 2,26688 R-Sq = 93,1%
R-Sq(adj) = 91,3%

Regression Analysis: WF4 versus Y4
The regression equation is
WF4 = 69,30–0,3255 Y4
S = 1,84777 R-Sq = 96,1%
R-Sq(adj) = 95,1%

Regression Analysis: WF1 versus Y1
The regression equation is
WF1 = 75,00–0,09554 Y1
S = 0,369080 R-Sq = 98,8%
R-Sq(adj) = 98,3%

Based on the obtained equations, the yield indices of top-grade flour were calculated.

The optimal values of the conditioning parameters were determined using the method of contour-graphical analysis, where the following optimization criteria were used: the estimated yield of top-grade flour; maximum value of whiteness of flour; the ratio of the bran yield of break systems to the bran yield of reduction systems, as a characteristic of the grit formation efficiency; they amounted to moisture content of at least 15% and dwell time in the water of at least 18 hours, which corresponds to the recommendations. Thus, the introduction of flax seeds into the mixture does not affect the choice of conditioning parameters.

Mixing wheat grain with flax seeds during the processing of a grain mixture is a difficult task and is possible only immediately before milling, as they have significant differences in physical and chemical properties. In addition, this is based on the separate preparation of the components and self-sorting of the mixture during movement [12,13].

To determine the necessary conditions for the formation of a binary grain mixture, the main mixing methods were modeled:

- active — with a high relative speed of components movement, which are based on a convective movement mechanism (paddle mixers);
- passive — based on the movement of layers sliding relative to each other (drum mixers).

Evaluation of the quality of the mixture by the heterogeneity coefficient (coefficient of variation) was carried out according to the formula:

$$V = \frac{100}{\bar{c}}\sqrt{\frac{\sum_{1}^{n}(c_i - \bar{c})^2}{n-1}}, \% \qquad (1)$$

where
$\bar{c}$ — the arithmetic mean value of the key component concentration;
c_i — current concentration value;
n — the number of measurements.

The number of samples and the mass of the sample were determined in accordance with the recommendations [13] and amounted to — the number of samples — 8, the mass of the sample according to calculation — 5 g, in fact — 50 g.

Comparison of the mixing methods showed that the passive method is significantly inferior to the active one. So with equal mixing cycles, the coefficient V is 37.4% for the drum mixer and 15.9% for the screw mixer. Subsequently, the active mixing method was used, which ensured satisfactory quality. The basic scheme for the grain mixture preparing for milling includes: separate cleaning of wheat grain flow and flax seeds flow from impurities, cleaning of the surface (shelling) of wheat grain, wheat grain conditioning, wheat grain and flax seeds mixing, forming of a grain mixture flow.

The program of experimental studies of milling modes in the first, the second and the third break systems provided for a wide range of yield indices, which was achieved by a corresponding variation of the roll space: for the first break system from 0.75 mm to 0.20 mm, providing yield index from 25 to 70%, for the second break system from 0.20 mm to 0.05 mm, which corresponded to yield indices from 48 to 66%; for the third break system from 0.05 mm to 0.00, and the yield indices range was from 22 to 45%.

Analysis of the grain-size composition shows that the better part of the intermediate products lies in the size range of 600–150 microns (Figure 1).

The fractional composition of grains is shown in Figure 2.

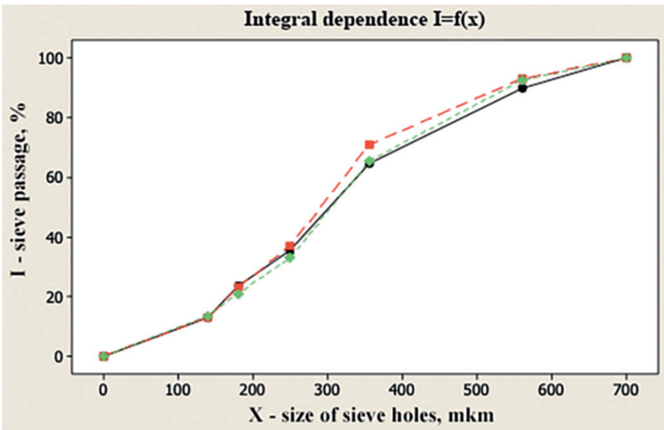

Figure 1. Grain-size composition of dunst products and flour obtained from I — III break systems with varying degrees of extraction: black color — 66%; red color — 72%; green color — 79%

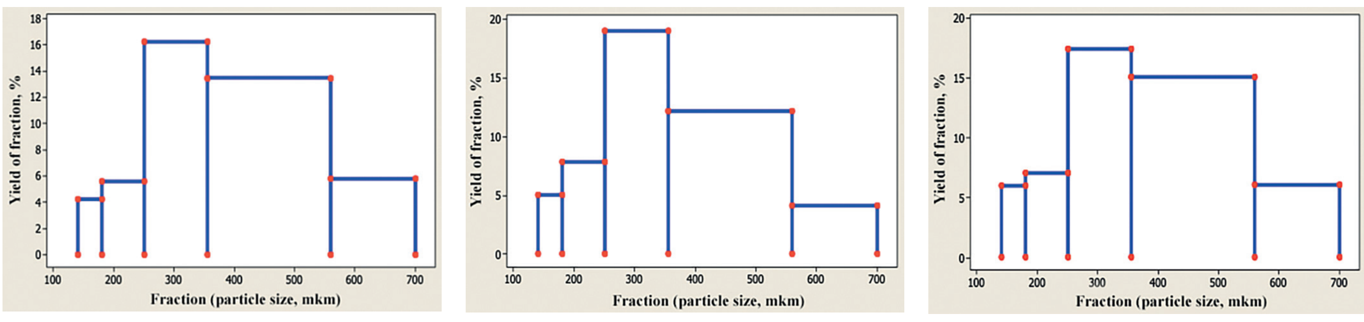

Figure 2. Fractional composition of grains obtained with I — III break systems with a total grains yield: a) — 43%: b) — 48%, c) — 52%

The bulk of the grains is characterized by a size of 250–560 microns, according to the classification [13] — this is a mixture of small and medium grains.

The optimal zone of the milling mode is determined, first of all, by the maximum endosperm content (minimum ash content) in the grains of break systems (Figure 3).

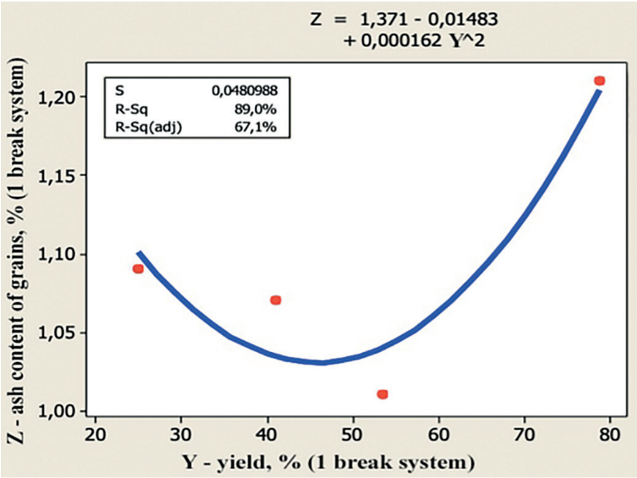

Figure 3. The dependence of the ash content of grains on the total yield (break I system)

The optimal milling conditions were characterized by the following values (yield / ash content): in terms of the first break system — 53.5 / 1.00; the second break system — 22.2 / 1.1; totally the first and the second break systems — 75.7 / 1.03 and the third break system — 5.3 / 2.07. Totally for the first, second and third break systems — 81.0 / 1.10.

Based on the analysis of the grains qualitative characteristics the principle scheme of a two-component grain mixture milling was formed, it included three break systems, one scratch, one sizing systems and five reduction systems. The yield of flour varied from 70 to 75%. The peculiarity of the technological scheme was that the break process was reduced, in fact, the selection of grains was carried out in the first and the second break systems, in the third break system only the dunst was selected. The flow of medium grains was directed to the sizing system, small grains were directed to the 1st reduction system and the dunst from the first, the second and the third break systems — to the 2nd reduction system.

Analysis of quantitative and qualitative characteristics of flour (yield, whiteness, ash) showed that the color of flax seeds has an important role in the market condition of flour and bread (Figure 4).

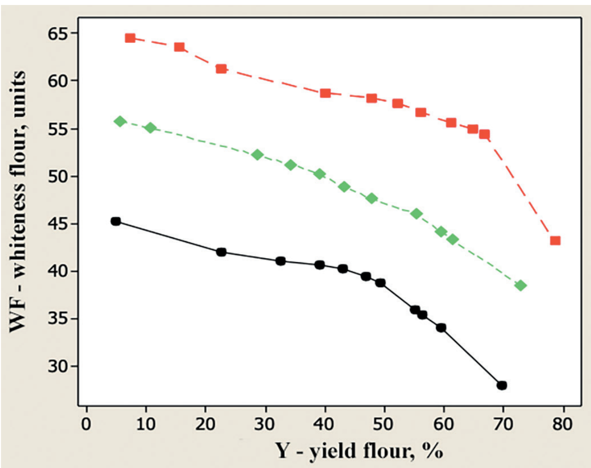

Figure 4. Cumulative curves of whiteness of flour: red color — wheat grain milling, black color — wheat + flax brown, green color — wheat + flax white

In addition, considering the non-uniform lipids distribution between individual flows, namely that the lipids content increases with the turn from the first to the last milling systems, and also taking into account the principle of the formation of flour varieties, which is based on the fact that the individual flows belong to different anatomical parts of the grain, flour varieties A, B and C were formed.

Variety A included flour flows from the central part of the endosperm — the first break system, the second break system, the sizing system, the first reduction system, the second reduction system, the third reduction system, — are characterized by low ash content and high whiteness value. Its yield was 45–50%, whiteness 50 units.

Variety B grade was obtained by mixing flour flows: third break system, the scratch system, the fourth reduction system, the fifth reduction system. It represents the crushed peripheral parts of the grain with a yield of 20–25% and a whiteness of 22 units.

Variety of flour C was obtained as a result of combining all flows of flour with a yield of 70–75% and a whiteness of 36 units.

The chemical composition of the formed flour varieties A, B, C, presented in Table 6, indicates the enrichment of wheat flour with protein and fat components, as well as fiber due to the inclusion of flax seeds in the binary grain mixture.

An analysis of the chemical composition of the formed flour varieties indicates an increase in the mass fraction of protein mass fraction by 1.0–2.0%, fat mass fraction in 1.5–3.5 times; fiber mass fraction by 3.4–4.0 times and a decrease in the mass fraction of starch by about 2–4%.

Table 6

The chemical composition of the formed varieties of flour

Sample	Protein (N × 6.25), %	Lipids, %	Starch, %	Cellulose, %	Reducing sugar, %
Wheat-flax flour, A variety	13.16	3.6	69.52	1.60	0.16
Wheat-flax flour, B variety	14.38	5.6	64.85	1.92	0.18
Wheat-flax flour, C variety	13.58	4.3	68.11	1.86	0.16
Wheat flour top grade (control)	12.65	1.6	72.10	0.46	0.14

The fractional composition of soluble proteins, the ratio of different fractions is important both for evaluating technological properties (gluten formation, its quantity and quality), and for the biological value of proteins, their assimilation degree [4,8,16,17,18,19]. The data presented in Table 7 demonstrate the ratio of soluble proteins fractions in the formed varieties of wheat-flax flour.

Table 7

The fractional composition of soluble proteins of the formed varieties of flour from a grain mixture based on wheat grain and flax seeds

Sample	The fractional composition of soluble proteins, % of the total				
	albumins	globulins	prolamins	glutelins	insoluble part
Wheat-flax flour, A variety	15.8	18.8	30.8	28.6	6.0
Wheat-flax flour B variety	13.2	18.5	29.6	29.8	7.8
Wheat-flax flour C variety	14.8	20.2	28.8	30.2	6.0
Wheat flour top grade (control)	8.4	17.0	35.8	30.8	8.0

The significant increase of the ratio of the albumin-globulin fraction content in wheat-flax flour samples to alcohol and alkali-soluble proteins content, as well as to its content in wheat flour, in which the part of gluten proteins prevails, should be marked.

When grain is processed into flour, the cell structure is destroyed, and as a result, oxidative and hydrolytic processes are enhanced [20]. In this regard, it is of interest to evaluate the activity of the main hydrolytic enzymes in samples of the formed varieties of wheat-flax flour. Thus, the value of proteolytic activity, along with other biochemical parameters, has fundamental importance, as proteinases are able to actively hydrolyze their own proteins, including the gluten ones, which, ultimately, affects the technological process and the finished product. In addition, proteolytic enzymes are involved in the regulation of the activity of other enzyme systems, for example, of amylases.

Amylases also assume major significance in assessing the quality of flour and products made from it. High amylolytic activity negatively affects its baking advantages.

In wheat flour, the substrate for the action of lipases is the flour's own lipids, the content of which can reach up to 1.5–2% of its mass, and in the studied samples of wheat-flax flour up to 3.6–5.6%. It is known that the use of lipase specimen leads to an improvement of the rheological properties of the dough, an increase of the specific volume of products, and an improvement of the crumb structure and color [4,5]. There is also evidence that lipases contribute to the retardation of the bread crumb, which can be explained by the action of hydrolysis products — monoglycerides and fatty acids, which, forming complexes with amylose, slow down its retrograde. It is supposed that lipases modify the interactions between proteins and lipids of flour, improving the gluten quality [19].

Moreover, lipolytic enzymes indirectly affect the oxidation processes in the dough during kneading, which is due to an increase of the availability of unsaturated fatty acids for the action of the lipoxygenase enzyme that is present in flour or introduced into the dough as part of improving agents.

Plant lipases are characterized by an optimum pH: cereal lipases mainly show their activity in the alkaline region — pH 8.0; oilseed lipases — In the acid region — pH 4.7 [21].

The unit activity of the main hydrolytic enzymes in the samples of the formed varieties of flour from a grain mixture based on wheat and flax seeds ispresented in Table 8.

Table 8

The unit activity of the main hydrolytic enzymes in the formed varieties of flour from a grain mixture based on wheat and flax seeds

Sample	UA* protease, units / mg protein		UA amylase units / mg protein	UA lipases, units / g	
	neutral	acid		alkaline	acid
Wheat-flax flour grade A	0.110	0.080	0.45	3.8	5.2
Wheat-flax flour grade B	0.120	0.090	0.60	3.8	6.0
Wheat-flax flour grade C	0.110	0.080	0.55	3.8	5.6
Wheat flour top grade (control)	0.100	0.070	0.50	3.8	0

* UA — unit activity

The unit activity of proteases and amylases in the studied samples of wheat-flax flour changes, but not significantly, and the activity of alkaline lipases (cereal lipases) remains unchanged, while the activity of acid lipases (oilseed lipases) is approximately 1.5 times higher than the activity of alkaline lipases in the studied samples of wheat-flax flour. As noted above, it occurs due to the presence of flax seed milling products and may affect the shelf life of this type of flour. However, the test samples storage in the laboratory at 4–6 °C for 14 weeks led to an insignificant increase of the acid lipases activity by 1.8–2.5%.

The fatty acid composition data (Table 9) of the formed flour varieties from a two-component grain mixture consisting of 93% of wheat and 7% of flax seeds allows us to draw the following conclusion: the content of linoleic acid (ω-6) in the wheat flour sample is 1.6 ... 3.3 times less than in the wheat-flax flour samples (0.93% against 1.51 ... 3.14%, taking into account the total lipids content in the samples); the content of linolenic acid (ω-3) in the wheat flour sample is 36.8 ... 57.2 times less than in the wheat-flax flour samples (0.047% against 1.73 ... 2.69%, taking into account the total lipids content in the samples).

Table 9

The fatty acid composition of the formed varieties of flour from a two-component grain mixture consisting of 93% of wheat grain and 7% of flax seeds

Indicator	The content of high fatty acids, %			
	wheat flour, top grade	wheat-flax flour, grade A	wheat-flax flour, grade B	wheat-flax, flour grade C
C 14: 0 myristic	< 0.1	< 0.1	< 0.1	< 0.1
C 16: 0 palmitic	19.64 ± 1.57	18.79 ± 7.50	12.54 ± 1.00	15.44 ± 1.24
C 16: 1 palmitoleic	< 0.1	< 0.1	< 0.1	< 0..1
C 17: 0 margarine	< 0.1	< 0.1	< 0.1	< 0.1
C 17: 1 margaroleic	< 0.1	< 0.1	< 0.1	< 0.1
C 18: 0 stearic	1.21 ± 0.13	5.79 ± 0.46	4.81 ± 0.53	5.26 ± 0.42
C 18: 1 oleic	17.54 ± 1.40	28.50 ± 1.43	22.54 ± 1.8	25.15 ± 0.02
C 18: 2 linoleic	**57.95 ± 2.90**	**41.21 ± 3.06**	**55.57 ± 2.78**	**49.97 ± 2.46**
C 18: 3 linolenic	**2.95 ± 0.32**	**48.80 ± 0.54**	**39.23 ± 0..43**	**45.10 ± 0.45**
C 20: 0 arachin	< 0.1	0.25 ± 0.03	0.17 ± 0.02	< 0.1
C 20: 1 gondoin	0.73 ± 0.08	0.58 ± 0.06	0.39 ± 0.04	0.31 ± 0.03
C 20: 2 eicosodienoic	< 0.1	< 0.1	< 0.1	< 0.1
C 22: 0 behennaya	< 0.1	0.29 ± 0.03	0.15 ± 0.02	0.15 ± 0.02
C 22: 1 eruca	< 0.1	< 0.1	< 0.1	< 0.1
C 22: 2 docosodienic	< 0.1	< 0.1	< 0.1	< 0.1

Conclusions

Technological schemes for the preparation and milling of two-component grain mixtures based on wheat grain and flax seeds are developed. The patterns of preparation and milling of binary grain mixtures to obtain composite types of flour with specified technological properties and increased nutritional value on account of the enrichment of the traditional types of grain by adding flax seeds with valuable nutritional components such as PUFA, essential amino acids, and other irreplaceable nutritional factors are revealed.

The use of whole flax seed in a binary grain mixture, consisting of 93% of wheat and 7% of flax seeds, allowed to balance the chemical composition of composite wheat-flax flour by the protein and lipids components, and also to enrich it with fiber, which means to use the entire phytopotential of flax seeds. Primarily, as the studies showed, the obtained wheat-flax flour contains the sufficient amount of PUFA in accordance with the recommended standards for consumption of grain-based food products [10], and the products made from it will help to make up the deficiency of ω-3 family PUFA in the diet of a modern person.

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